Flow Modeling for the Frio Brine Pilot

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Fourth Annual Conference on Carbon Capture & Sequestration

Geologic – Frio Brine Field Project (1)

Flow Modeling for the Frio Brine Pilot

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Outline

- Purposes of modeling
- Model development
- Model applications
- Conclusions and future directions

Purposes of Modeling

- Planning – to help design Frio brine pilot
- Predictions – to assess state of understanding
- Calibration – to improve understanding of the multi-phase, multi-component flow processes involved in geologic sequestration of CO_2

Experiment Design Issues

Requirement	Controlling factors	Decision
Pressure increase must be within regulatory limits	• permeability • outer boundary conditions • CO_2 injection rate	• ΔP should be okay for highest planned CO_2 injection rate
CO_2 must arrive at observation well	• thickness of injection interval • well separation • amount of CO_2 injected	•Drill new injection well closer to observation well
Duration of field test must be affordable	• thickness of injection interval • well separation • CO_2 injection rate	•Inject into C sand above thin marker bed •Highest CO_2 injection rate
CO_2 must be monitored in subsurface	• amount of CO_2 injected • in situ phase/component conditions	•Downhole P, T •VSP •Cross-well seismic

Outline

- Purposes of modeling
- Model development
  - Numerical simulator TOUGH2
  - Key physical processes
  - Incremental model development
- Model applications
- Conclusions and future directions

Numerical Simulator TOUGH2

- General-purpose simulator for flow and transport through porous or fractured rock
  - multi-component
  - multi-phase
  - heat flow
  - tracer transport
- Equation of state: CO_2, H_2O, NaCl, ideal tracer
- Accurate phase partitioning and thermophysical properties
  - CO_2: liquid, gas, supercritical, dissolved
  - H_2O: liquid, gas
  - NaCl: dissolved, precipitate
- Integral-finite difference method for flexible space discretization
- Fully implicit, fully coupled time-stepping

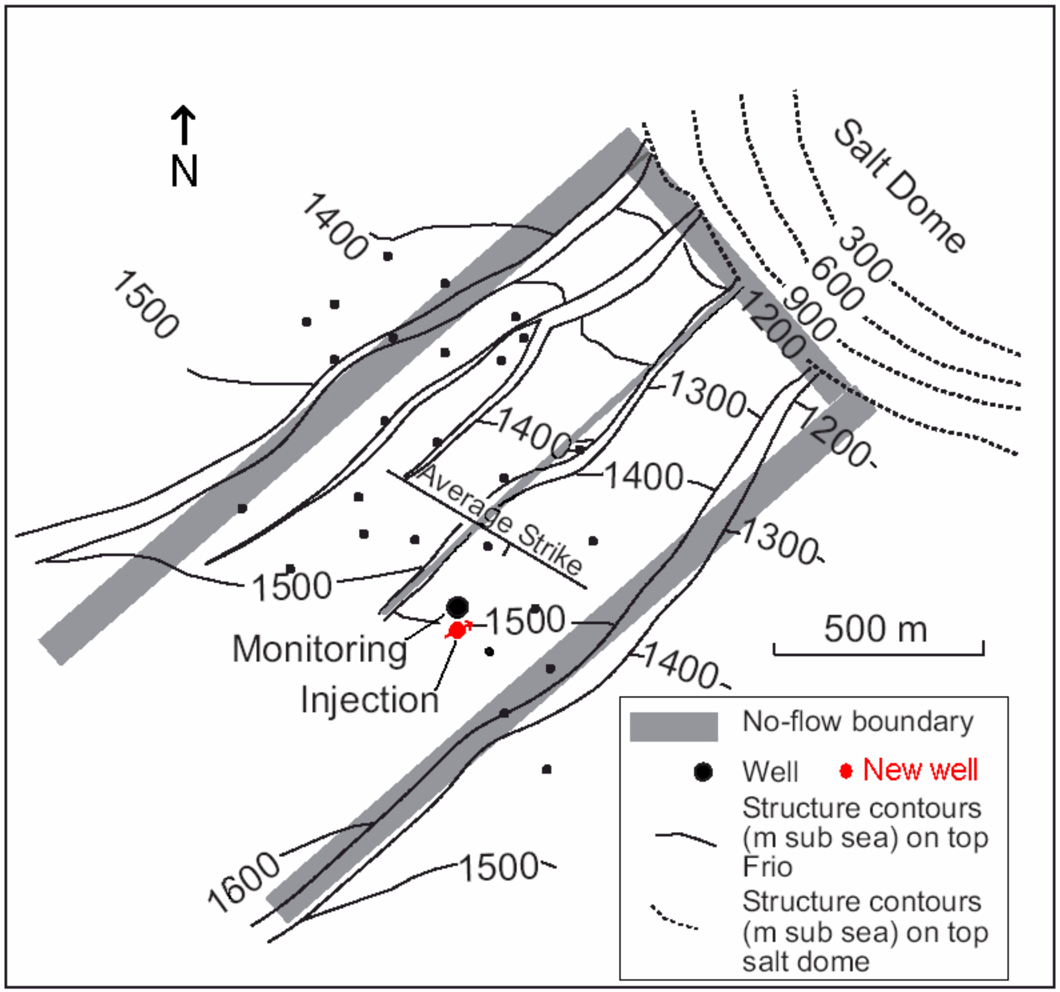
Key Physical Processes

- Flow equations: multi-phase Darcy's Law for phase β

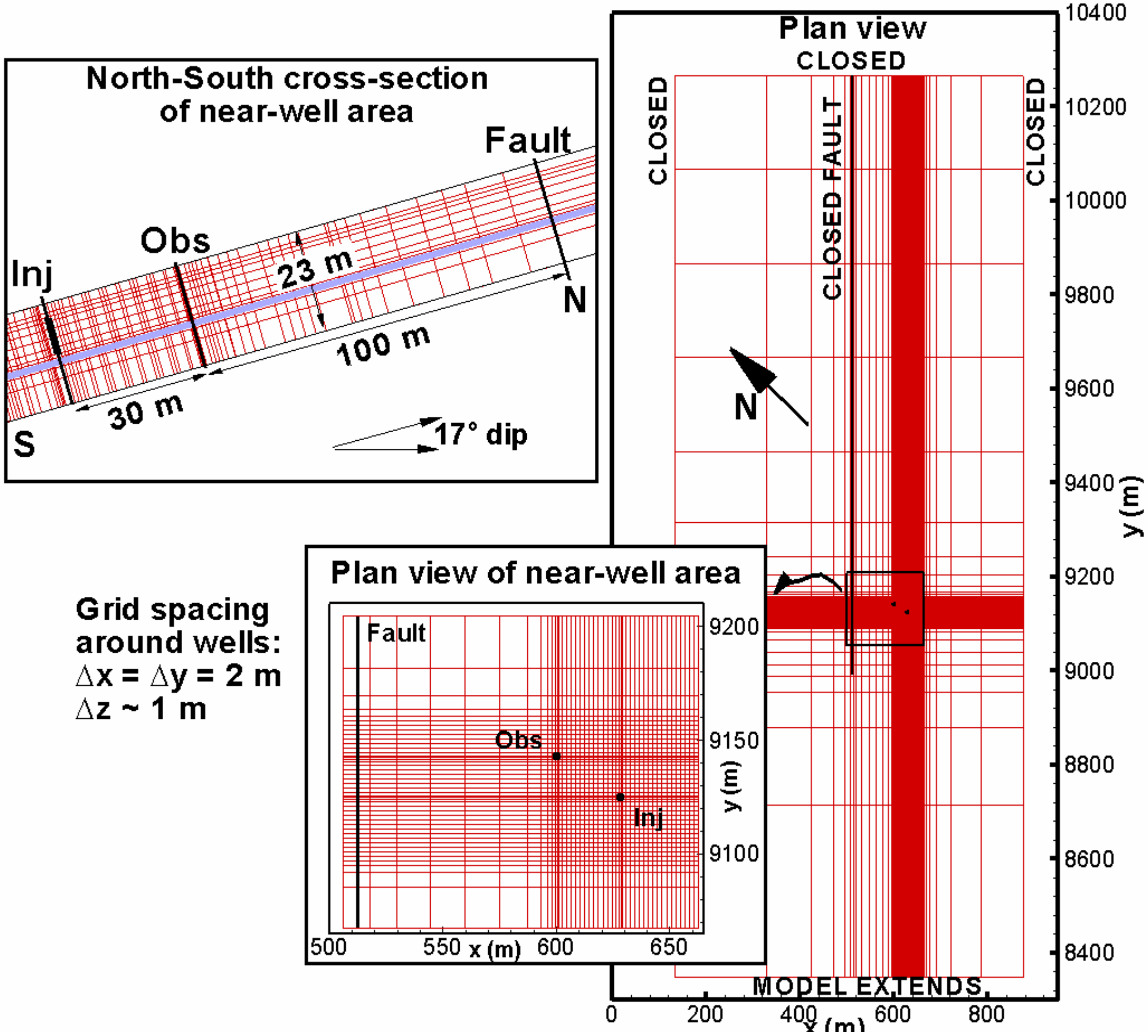
$$q_\beta = -K_\beta\left(\nabla P_\beta - \rho_\beta g\right) \qquad K_\beta = \frac{k k_{r\beta}\rho_\beta}{\mu_\beta}$$

- Mobility K_β includes intrinsic permeability k, relative permeability $k_{r\beta}$, density ρ_β, and viscosity μ_β
- Driving forces
  - Pressure gradient (including capillary pressure P_{cap})
  - Gravity
- Key properties of supercritical CO_2 at Frio conditions (150 bars, 55°C)
  - Low ρ and μ compared to surrounding brine
  - $k_{r\beta}$ and P_{cap} control phase interference between CO_2 and brine

Plan View and Model Boundaries



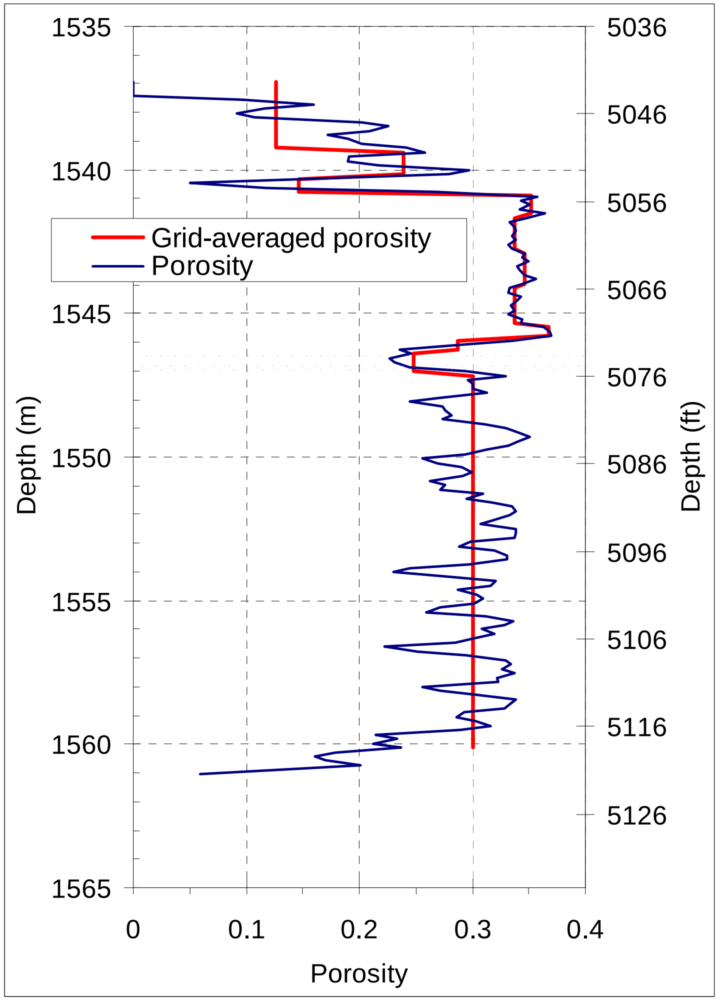
3-D Grid Design

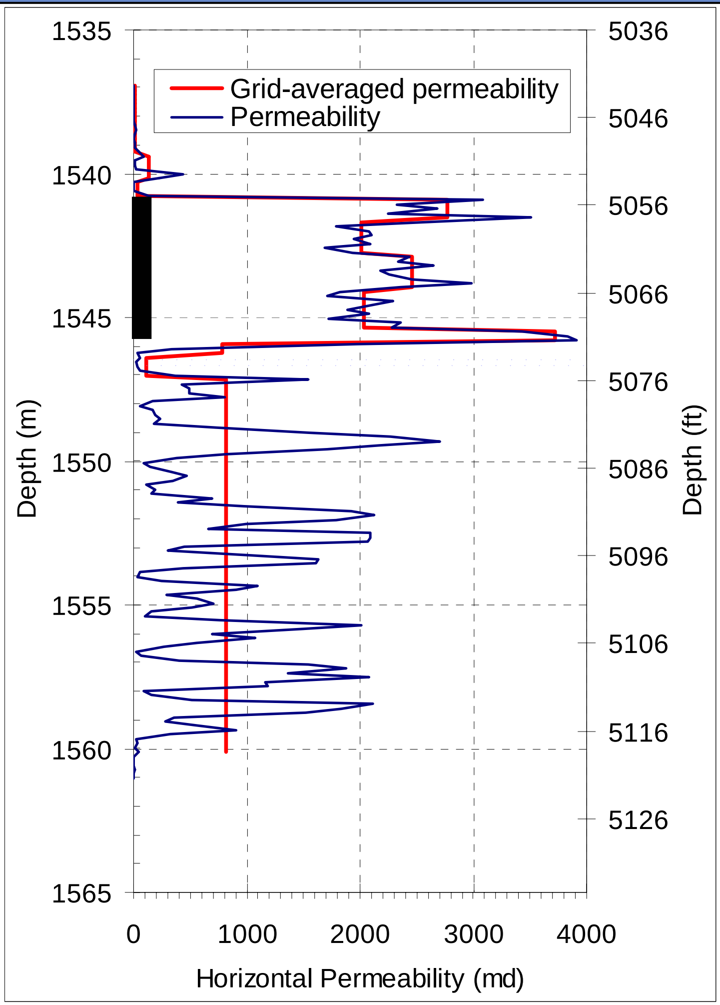


Grid spacing around wells:
$\Delta x = \Delta y = 2$ m
$\Delta z \sim 1$ m

Property Assignment

Well Logs and Core Analysis





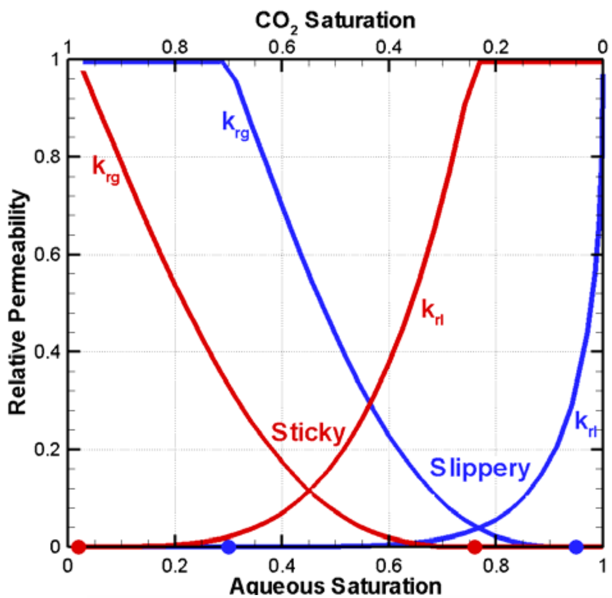
Data provided by Shinichi Sakurai, TBEG

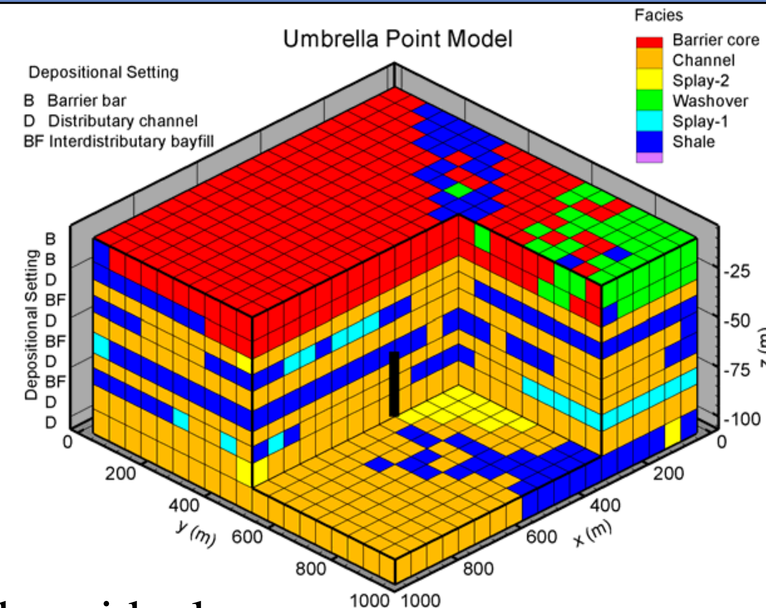
Outline

- Purposes of modeling
- Model development
- Model applications
  - Estimation of relative permeability curves
- Conclusions and future directions

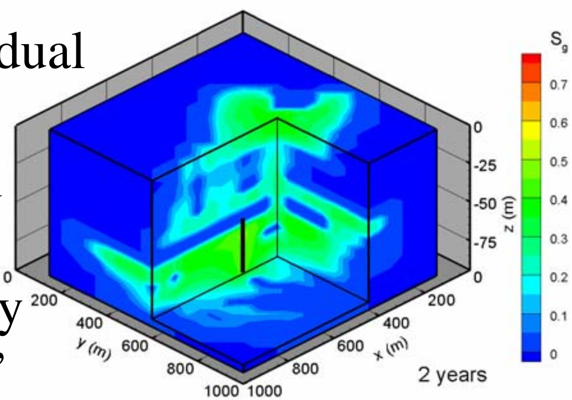
Relative Permeability Function

Sticky or Slippery Plume?



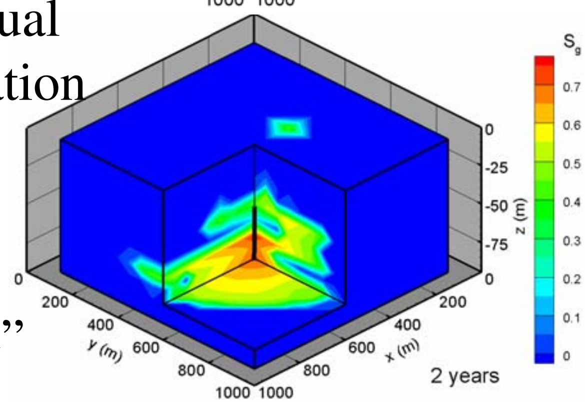


Low residual CO_2 saturation



"Slippery Plume"

High residual CO_2 saturation

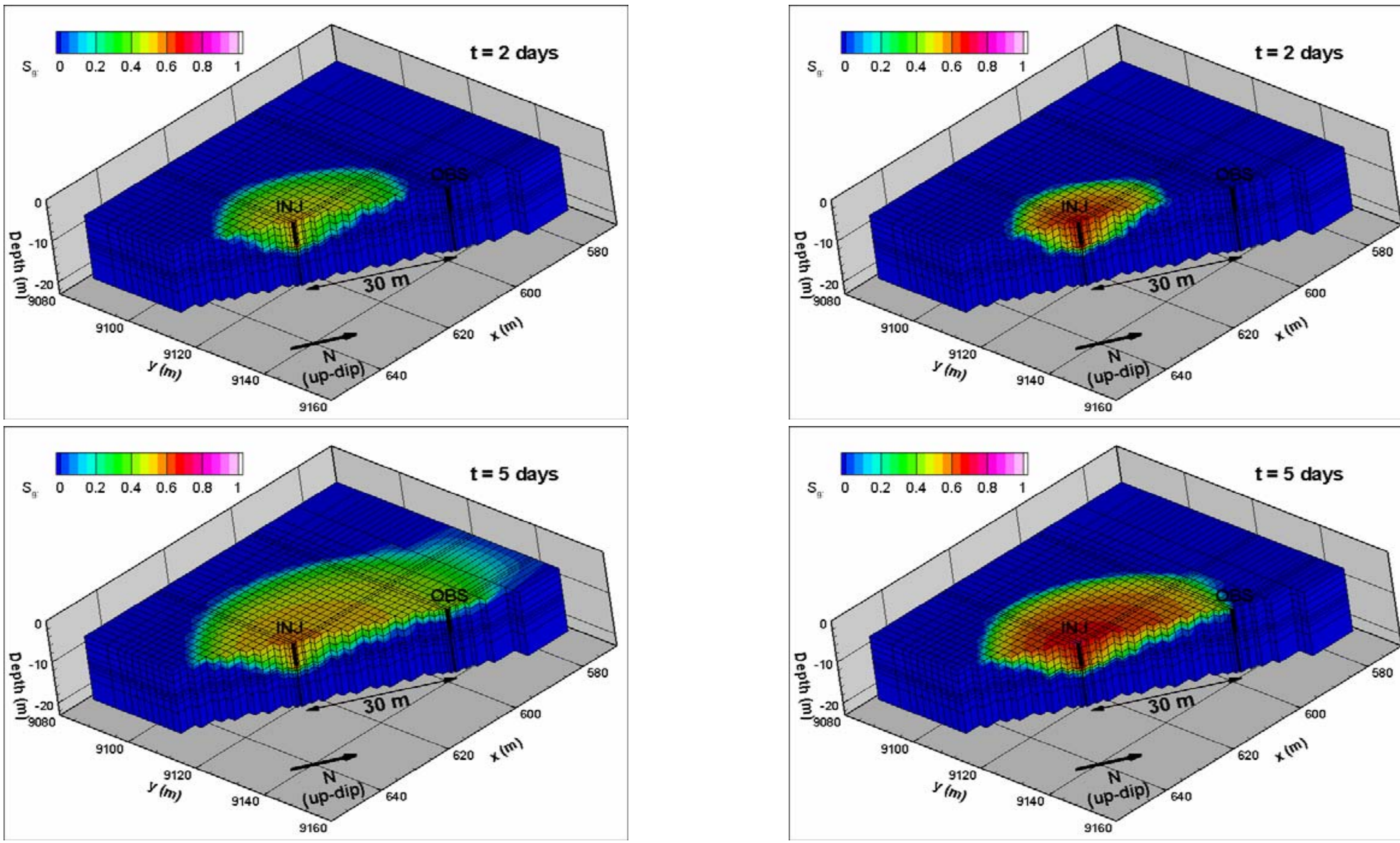


"Sticky Plume"

Modeled CO_2 Distribution

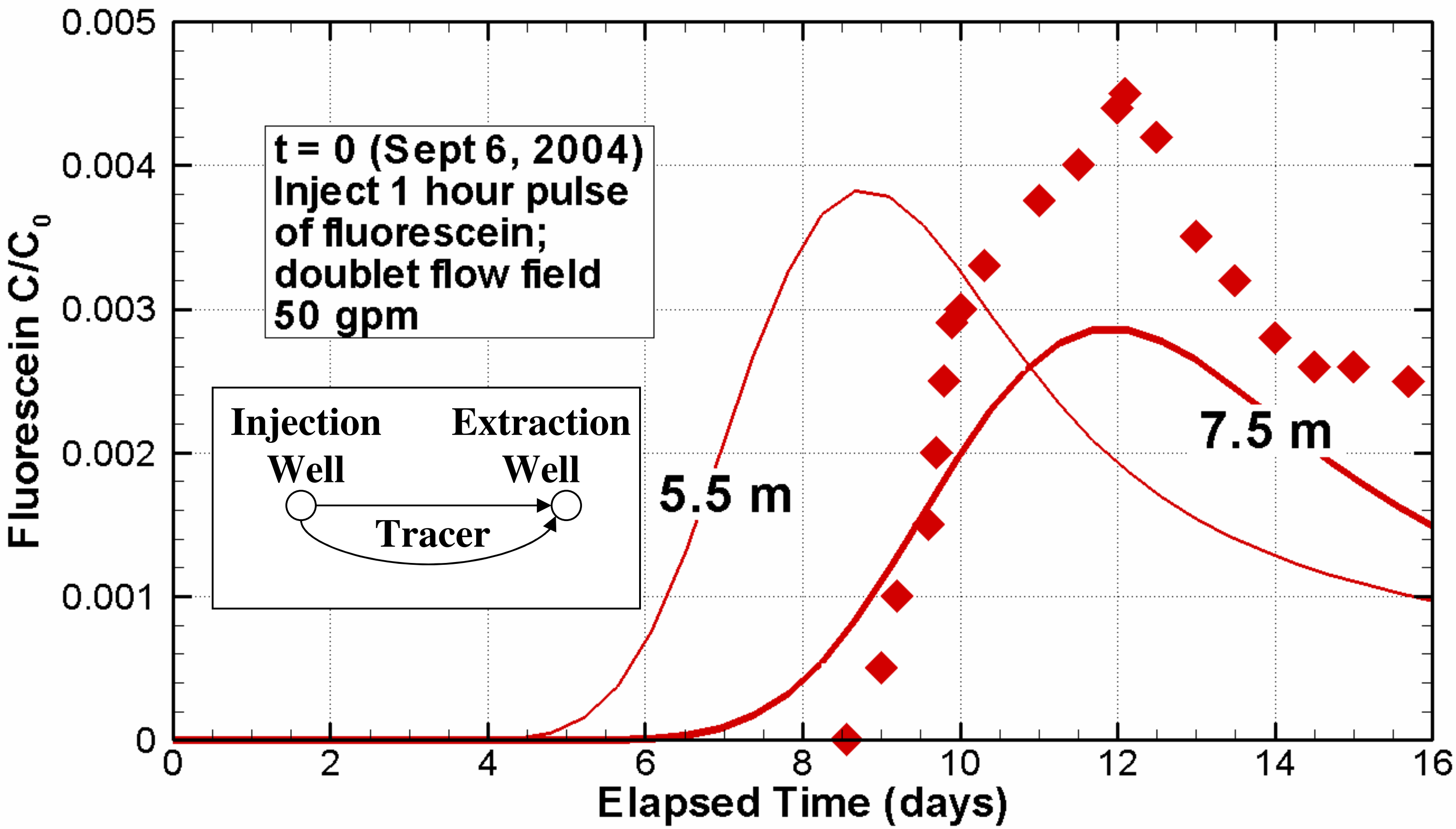
Slippery plume - arrival 3 days

Sticky plume - arrival 5 days



Site Characterization

Tracer-Test Arrival for Two C Sand Thicknesses

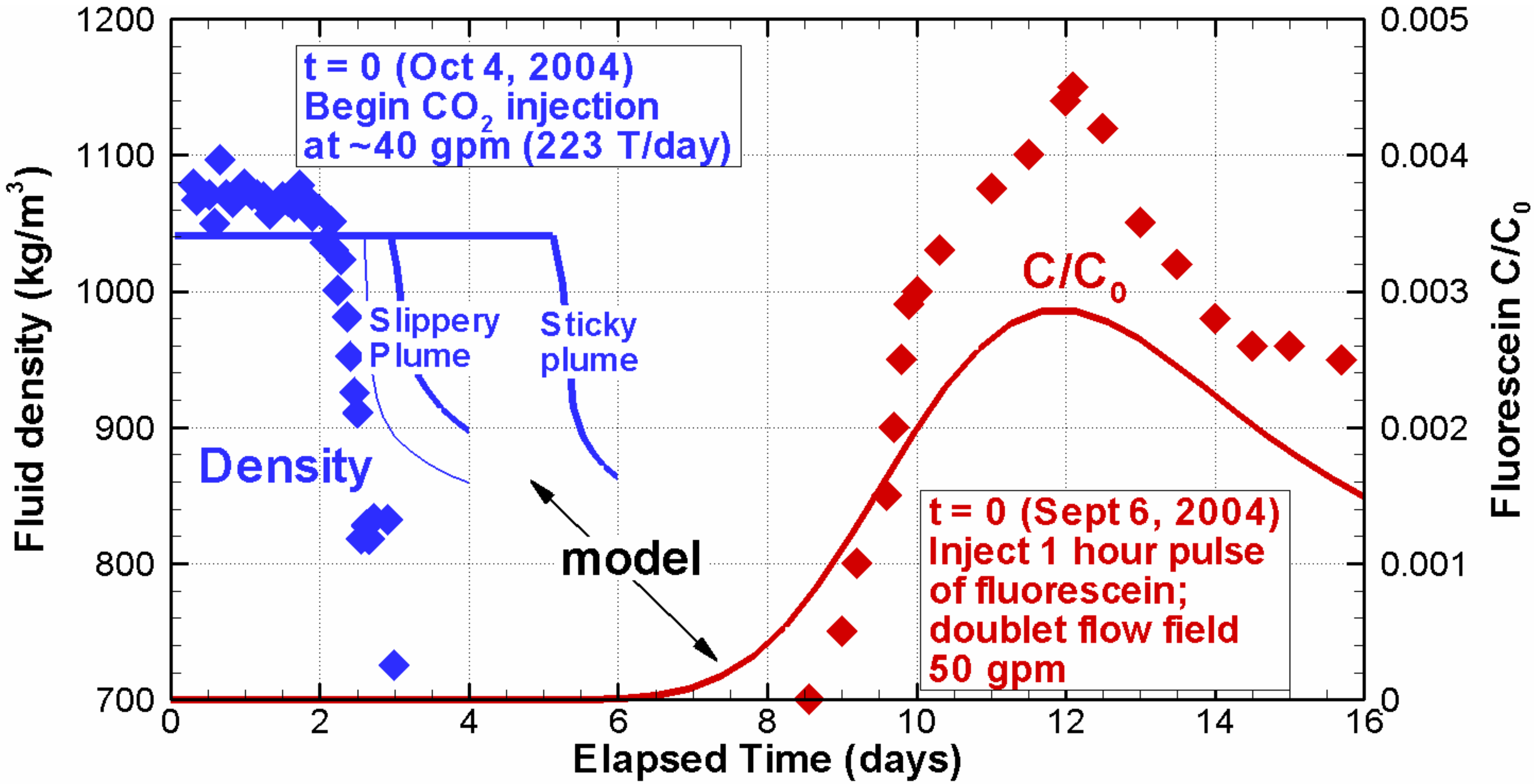


Data provided by Barry Freifeld and Rob Trautz, LBNL

Use Tracer-Test to Predict CO_2 Arrival

Feature	Tracer Test	CO_2 Injection	Impact on CO_2 Arrival Time
Flow field	Doublet	Single well	3 times slower
Phase conditions	Single-phase	Two-phase	Faster
Density contrast	None	1.5	Faster
Viscosity contrast	None	12	Faster
Injection rate	50 gpm	40 gpm	20% slower
Density in situ	1060 kg/m^3	~700 kg/m^3	50% faster
Arrival at observation well	9 days (peak 12 days)	WITHIN TWO WEEKS???	

Observed Data and Model Predictions



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RST – Reservoir Saturation Tool

RST Interpretation

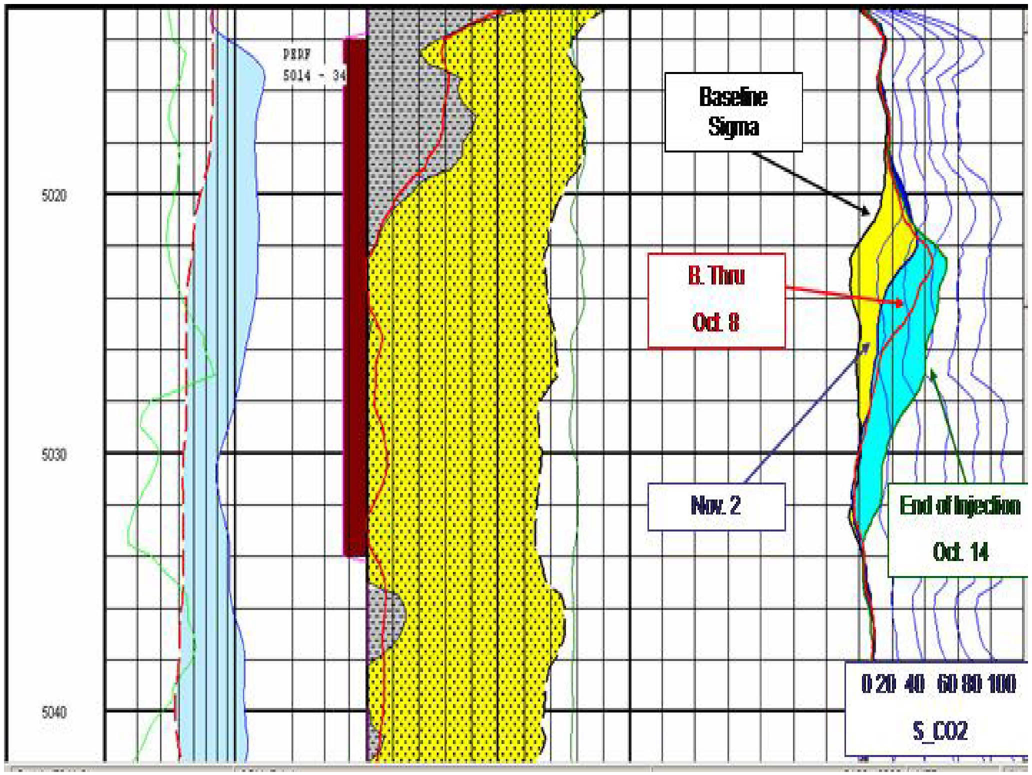
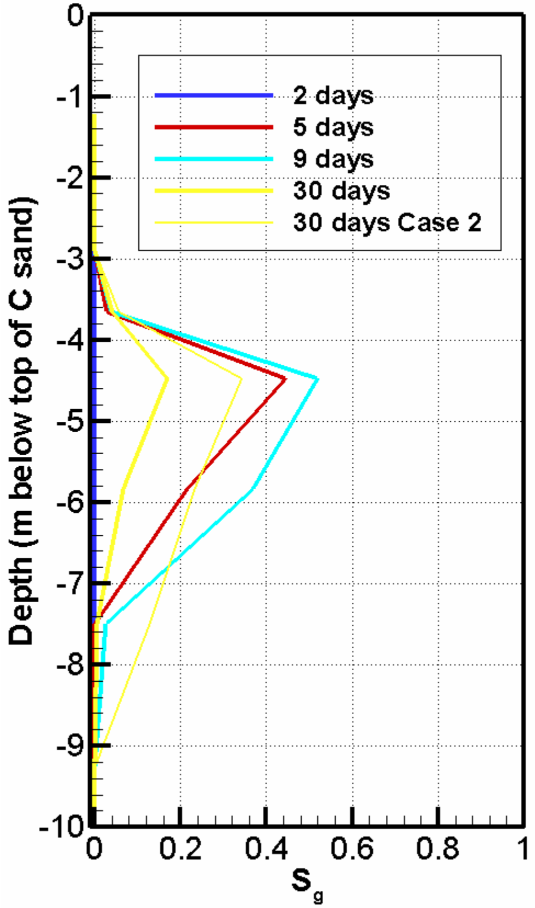


Figure provided by Shinichi Sakurai, TBEG
RST logging conducted by Schlumberger

Model



Conclusions and Future Directions

- Developing good understanding of physical process involved in CO_2 storage
  - modeling range of behaviors
  - comparing to field data
- Complex interplay between phase interference and buoyancy flow for CO_2 injection into a high-permeability, steeply dipping sand layer
- Prepared to design future tests and actual storage operations
- Still to learn
  - Phase interference at field scale
  - Upscale from laboratory experiments
  - Dynamics of trailing edge of CO_2 plume

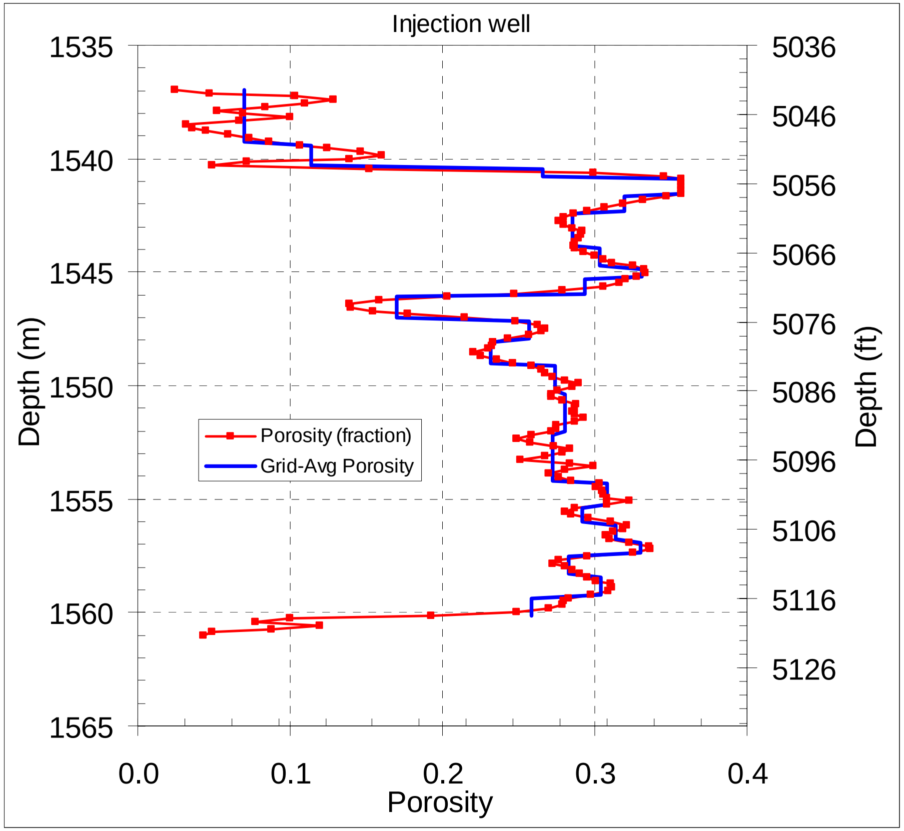
Site Characterization

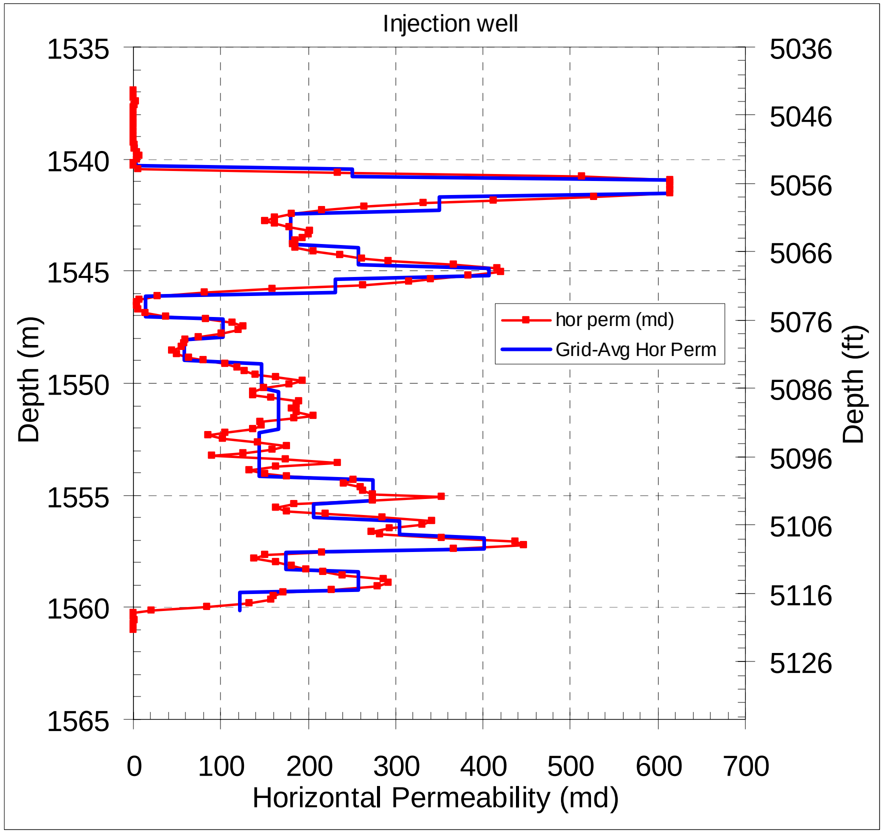
Well-Test Design and Analysis

- Simulate well-test scenarios to design well-testing to optimize information gained on
  - flow properties
  - in situ phase conditions (dissolved or immobile methane)
  - fault-block boundary conditions
- Simulate actual well-test and compare to observed data
  - confirms high permeability values of core analysis
  - suggests nearby small fault may be non-sealing (could enable communication between C and B sands)

Property Assignment

New Injection Well Logs





Data provided by Mark Holtz, TBEG

Incremental Model Development

Date	**Data incorporated**	**Model Application**	**CO_2 Arrival Time (days)**
8/01	Regional Frio and Anahuac geology South Liberty oil-field data: 50-year-old well logs, 3D seismic	CO_2 injection: B sand, wells 150 m apart C sand, wells 30 m apart	 45 2
9/02	Large S_{gr} from Frio literature	CO_2 injection	4
8/03	More geological structure	CO_2 injection	3 - 6
6/04	New injection well logs	CO_2 injection	4 - 7
8/04	Core analysis	Well test	
9/04	Well test	Tracer test: t_{peak} = 9 d CO_2 injection	2.7 – 5.0
9/04	Tracer test	Tracer test: t_{peak} = 12 d CO_2 injection	3.2 - 6.1
3/05	CO_2 injection (t_{bt} = 2.2 d)	Long-term CO_2 plume evolution	